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Electrostatic Precipitator Cost for Large Coal-Fired Steam Generators

Industrial Gas Cleaning Inst, Inc, Stamford, CT

Prepared for

Environmental Protection Agency, Research Triangle Park, NC

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ELECTROSTATIC PRECIPITATOR COSTS FOR LARGE COAL-FIRED STEAM GENERATORS

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16. ABSTRACT

Capital and annualized costs for electrostatic precipitators for use on large coal-fired steam generators are estimated for a variety of conditions:

a. Boiler sizes of 200 and 700 megawatts

b. Hot and cold side units

c. Emission standards of 13, 22, and 43 nanograms per joule (0.03, 0.05, and 0.10 Lbs particulate per million Btus)

d. Low and high resistivity coal

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ELECTROSTATIC PRECIPITATOR COSTS

FOR

LARGE COAL-FIRED STEAM GENERATORS

Prepared by

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Stamford, Connecticut 06904

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1.0 INTRODUCTION

The purposes of this task are:

1) To determine the costs for electrostatic precipitators to control particulate emissions from large coal-fired steam generators, such costs to be a function of different coal types, boiler sizes, and emission limits;

2) To identify the total costs that will result from the addition of electrostatic precipitators to the proposed new generating capacity in the United States, factoring into these costs coal types, emission limits, and boiler sizes.

The scope is confined to the development of capital and annualized costs of electrostatic precipitators on boilers using pulverized coal for fuel. Capital costs include those for the precipitator, inlet and outlet duct transitions, foundation and supporting steel, and precipitator erection, as well as related painting, electrical work, and insulation. Indirect installation costs, which include engineering, construction, field expenses and fees, start-up, and contingencies, are to be itemized and added to the direct costs to yield a turnkey cost.

Model studies for the precipitator gas distribution systems are not included since such studies are site specific.

Costs include the piping and valve components of a fly ash collection and handling system from the precipitator hoppers.

Annualized costs are defined as the direct costs of precipitator operation plus fixed costs for overhead and capitalization. Fly ash handling costs are excluded, since utilities operate fly ash and bottom ash handling facilities as a combined system.

The specifications prepared cover electrostatic precipitators that treat flue gas resulting from the following combination of variables:

Boiler size, MW	Coal	ESP type	Emission regulation, nanograms/joule	(lbs./10^6 Btu)
200	Best	Cold	43	(0.1)
200	Best	Cold	13	(0.03)
200	Worst	Cold	43	(0.1)
200	Worst	Cold	22	(0.05)
200	Worst	Cold	13	(0.03)
200	Worst	Hot	22	(0.05)
200	Worst	Hot	13	(0.03)
700	Best	Cold	43	(0.1)
700	Best	Cold	13	(0.03)
700	Worst	Cold	43	(0.1)
700	Worst	Cold	13	(0.03)
700	Worst	Hot	22	(0.05)
700	Worst	Hot	13	(0.03)

The specifications were sent to three IGCI members recommended by the Engineering Standards Committee as being

expert in this field of application. Copies of the specifications are included in the Appendix.

For purposes of comparison, gas volume output from the two types of coal utilized is taken as the same. In actual practice, gas volume would differ for a variety of reasons, primarily the calorific value.

When these quotations were received, they were tabulated and averaged; then estimated installed costs of valving and piping for an ash handling system were added to this figure. The cost values so established were used in conjunction with coal usage data for projected new boilers to arrive at the costs to be considered in future boiler construction for compliance with various particulate emission control regulations.

It should be understood that the efficiency data provided in this study is the normal design value. This value should be obtained when the collection equipment is in good operating condition and within the design flow specifications. There is, however, no assurance that these specifications will be in effect 100% of the time, due to unforeseen upsets in the process gas flows or conditions. These conditions include, but are not limited to, a change in process chemistry, a change in size distribution of suspended particulate matter, or an excessive dust load. Normal, good maintenance procedures must be employed to meet the continuous high level efficiency requirements.

2.0 PROCESS DESCRIPTION

A coal-fired utility boiler employing an electrostatic precipitator for particulate emission control is diagramed in Figure 2-1. As shown in the figure, air is blown into the boiler by forced draft fans. To achieve heating economy, the air is preheated by passage through a steam coil preheater and then an air heater to recover heat from the hot exhaust gases. In the boiler, pulverized coal is burned with the preheated air to generate steam from boiler feedwater.

Coal combustion produces ash, which is non-combustible coal residue, and hot gases. While a small amount of the ash falls to the bottom of the combustion chamber and is subsequently removed as bottom ash, a considerable amount, called "fly ash" (70 to 95%) is entrained in the hot gas stream. The fine particle size of this material makes it difficult to separate from the combustion gas stream.

An electrostatic precipitator (ESP) is used to remove this fly ash from the boiler exhaust gases. If it is located before the air heater, it is called a "hot side" ESP; if located after, a "cold side" ESP. Figure 2-1 illustrates a cold-side ESP.

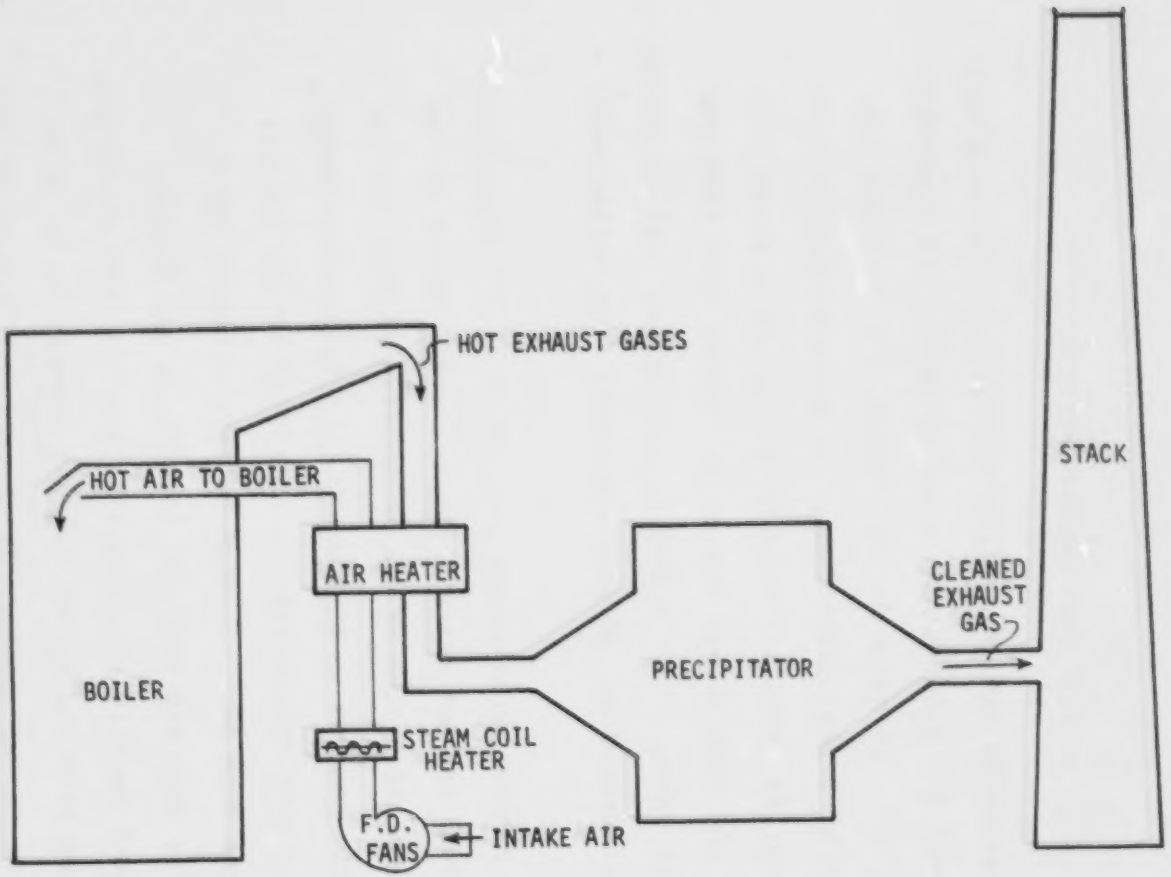

Figure 2-1. Diagram of gas flow for a cold side electrostatic precipitator on a coal-fired utility boiler.

A hot-side or a cold-side precipitator for a particular boiler installation is selected on an economic basis, depending upon the type of coal burned, the method of firing, and the level of emissions control required. The chemical composition of the ash has a profound effect on fly ash resistivity, and thus on precipitator performance. The type of fuel has been defined as worst and best for this report.

For this task, pulverized coal firing was specified, and analyses of a worst[a] and a best[a] coal were set forth (see specifications in the Appendix) to permit development of investment and operating costs for three emission control levels and two boiler sizes.

When boiler exhaust gases pass through the electrostatic precipitator, fly ash particles contained in the gas become electrically charged and migrate to the electrodes, where they adhere by electrostatic force. Periodic rapping of the electrodes causes the accumulated particles to fall into collecting hoppers located below the precipitators. The cleaned exhaust gases are sent either to a tall stack for discharge to the atmosphere or to a flue gas desulfurization system for removal of sulfur dioxide before being discharged.

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[a] Worst coal implies high electrostatic precipitator requirements; best coal implies low electrostatic precipitator requirements.

When the fly ash particulate matter collected in the hoppers reaches a specified level, timed cycle operated valves discharge it to a pneumatic conveying system for transport to disposal.

3.0 PARTICULATE EMISSION CONTROL BY ELECTROSTATIC PRECIPITATOR

3.1 DESIGN SPECIFICATIONS

The design specification and the thirteen variant conditions for electrostatic precipitator operation are presented in the Appendix.

As shown at the top of each sheet, the percentage of sulfur in the coal used is either 4 or 0.5 percent. The higher percentage designates best coal; the lower one indicates worst coal.

The gas temperature indicates the precipitator location, 700°F for hot-side and 350°F for cold-side.

The precipitator efficiency and residual particulate emission values shown are directly correlated to the three emission control levels considered - 13, 22, and 43 nanograms per joule (0.03, 0.05, and 0.1 $lb/10^6$ Btu).

3.2 CAPITAL INVESTMENT COSTS

The capital investment required for precipitators operating under various conditions and particulate emission control levels is presented in Table 3-1 for 200-MW boilers and in Table 3-2 for 700-MW boilers.

The various cost items shown represent the sum of the precipitator costs and estimated installed costs of piping and valves for a fly ash handling system. Precipitator auxiliary equipment typically includes access and supports, a purge air system, and hopper heaters. Other components of an ash handling system, such as storage silos, conveying systems, unloader and controls, are not included. Also, no fans are included for air movement.

Duct and stack costs are not included in the direct costs for installation since only flange-to-flange costs of electrostatic precipitators are being considered.

3.3 ANNUALIZED OPERATING COSTS

Tables 3-3 and 3-4 show the estimated total cost of operating an electrostatic precipitator, under the various conditions, on 200- and 700-MW units, respectively. These costs are predicated upon operation of the precipitators at 65 percent load factor.

The total costs comprise the average of the direct operating costs submitted by the three IGCI members and the computed overhead and capitalization charges. Fan operating costs for air movement or ash conveying are not included.

Table 3-1. INVESTMENT COSTS FOR ELECTROSTATIC PRECIPITATORS ON 200 MW UTILITY BOILERS

(December 1976)

Boiler size, MW	200	200	200	200	200	200	200
Precipitator location	Cold	Cold	Cold	Cold	Cold	Hot	Hot
Coal type	Best	Best	Worst	Worst	Worst	Worst	Worst
Inlet and Outlet Gas Flow							
acfm	798,000	798,000	798,000	798,000	798,000	985,000	985,000
°F	350	350	350	350	350	700	700
scfm	521,000	521,000	521,000	521,000	521,000	450,000	450,000
Moisture, Vol. %	10	10	10	10	10	10	10
Particulate Loading							
Inlet gr/acf	2.32	2.32	1.76	1.76	1.76	1.43	1.43
Inlet lb/hr	15,900	15,900	12,000	12,000	12,000	12,000	12,000
Outlet gr/acf	0.03	0.009	0.03	0.015	0.009	0.012	0.007
Outlet lb/hr	200	60	200	100	60	100	60
Removal efficiency, %	98.7	99.6	98.3	99.2	99.4	99.2	99.5
Emission Control Level,							
ng/joule	43	13	43	22	13	22	13
(lb./10^6 Btu)	(0.1)	(0.03)	(0.1)	(0.05)	(0.03)	(0.05)	(0.03)
Equipment Costs							
Device	913,100	1,227,200	1,361,500	1,828,900	2,046,100	1,546,100	1,837,000
Auxiliary equipment	154,600	171,500	174,700	191,900	207,600	190,200	196,000
Ash handling equipment	35,600	47,500	47,500	62,500	75,600	47,500	62,500
Total	1,103,300	1,446,200	1,583,700	2,083,300	2,329,300	1,783,800	2,095,500
Installation Costs - Direct							
Foundation and supports	114,300	130,800	134,300	157,400	173,000	151,900	166,600
Insulation	247,200	296,600	304,400	397,700	436,600	388,700	424,700
Painting	5,000	5,000	5,000	5,600	5,600	5,300	5,600
Electrical	78,600	116,600	103,600	156,300	181,600	133,300	205,300
Other	614,400	778,400	857,500	1,120,000	1,281,900	949,200	1,144,200
Total	1,059,500	1,327,400	1,404,800	1,837,000	2,078,700	1,628,400	1,946,400
Installation Costs - Indirect							
Engineering	126,200	127,700	127,700	129,600	131,200	127,700	129,600
Construction & field expense	67,600	81,900	89,100	109,300	127,700	89,600	107,000
Construction fees	26,200	27,000	27,000	28,000	28,900	27,000	28,000
Start-up	10,700	10,900	10,900	11,100	11,900	11,100	12,300
Performance tests	26,200	25,000	26,200	25,800	25,800	25,800	25,800
Contingencies	48,400	58,800	61,500	74,100	87,800	64,600	76,000
Total	305,300	332,000	342,400	377,900	413,100	345,800	378,700
Total turnkey cost	$2,468,100	$3,105,600	$3,330,900	$4,298,200	$4,821,100	$3,758,000	$4,420,600
$/kW investment	12.34	15.53	16.65	21.49	24.11	18.79	22.10

Table 3-2. INVESTMENT COSTS FOR ELECTROSTATIC PRECIPITATORS ON 700 MW UTILITY BOILERS

(December 1976)

Boiler Size, MW	700	700	700	700	700	700
Precipitator Location	Cold	Cold	Cold	Cold	Hot	Hot
Coal Type	Best	Best	Worst	Worst	Worst	Worst
Inlet and Outlet Gas Flow						
acfm	2,790,000	2,790,000	2,790,000	2,790,000	3,450,000	3,450,000
°F	350	350	350	350	700	700
scfm	1,825,000	1,825,000	1,825,000	1,825,000	1,580,000	1,580,000
Moisture, Vol. %	10	10	10	10	10	10
Particulate Loading						
Inlet gr/acf	2.32	2.32	1.76	1.76	1.43	1.43
Inlet lb/hr	55,600	55,600	42,200	42,200	42,200	42,200
Outlet gr/acf	0.03	0.009	0.03	0.009	0.012	0.007
Outlet lb/hr	700	210	700	210	350	210
Removal efficiency, %	98.7	99.6	98.3	99.5	99.2	99.5
Emission Control Level						
ng/joule	43	13	43	13	22	13
(lb/10^6 Btu)	(0.1)	(0.03)	(0.1)	(0.03)	(0.05)	(0.03)
Equipment Costs						
Device	3,103,700	3,958,300	4,652,300	6,833,900	4,895,000	6,007,300
Auxiliary equipment	469,900	526,000	543,200	634,200	571,700	609,400
Ash handling equipment	122,400	167,000	167,000	256,200	167,000	212,700
Total	3,696,000	4,651,300	5,362,500	7,724,300	5,633,700	6,829,400
Installation Costs - Direct						
Foundation and supports	376,800	423,700	370,300	577,400	430,400	500,500
Insulation	847,800	988,600	1,033,700	1,357,700	1,206,600	1,372,000
Painting	9,400	10,600	9,400	13,100	7,200	7,200
Electrical	285,600	460,900	430,900	646,300	520,600	664,600
Other	1,987,800	2,487,200	2,705,100	4,028,000	2,934,200	3,574,900
Total	3,507,400	4,371,000	4,549,400	6,622,500	5,099,000	6,119,200
Installation Costs - Indirect						
Engineering	181,500	187,300	187,300	198,700	187,300	193,100
Construction and field expense	278,000	328,800	336,300	449,000	340,600	399,900
Construction fees	63,200	66,600	66,600	72,300	66,600	69,500
Start-up	28,200	32,000	28,600	35,800	32,100	36,300
Performance Tests	56,000	56,000	56,000	56,000	56,000	56,000
Contingencies	176,700	207,700	206,700	217,700	218,100	267,100
Total	783,600	878,400	881,500	1,029,500	900,700	1,021,900
Total Turnkey Cost	$7,987,000	$9,900,700	$10,793,400	$15,376,300	$11,633,400	$13,970,500
$/kW Investment	11.41	14.14	15.42	21.97	16.62	19.96

Table 3-3. ANNUALIZED OPERATING COSTS FOR ELECTROSTATIC PRECIPITATORS ON 200 MW UTILITY BOILERS

(December 1976)

Basis: 8,760 operating hours per year at 65% capacity factor

Boiler Size, MW		200	200	200	200	200	200	200
Precipitator Location		Cold	Cold	Cold	Cold	Cold	Hot	Hot
Coal Type		Best	Best	Worst	Worst	Worst	Worst	Worst
Inlet and Outlet Gas Flow								
acfm		798,000	798,000	798,000	798,000	798,000	985,000	985,000
°F		350	350	350	350	350	700	700
scfm		521,000	521,000	521,000	521,000	521,000	450,000	450,000
Moisture		10	10	10	10	10	10	10
Particulate Loading								
Inlet gr/scf		2.32	2.32	1.76	1.76	1.76	1.43	1.43
Inlet lb/hr		15,900	15,900	12,000	12,000	12,000	12,000	12,000
Out et gr/scf		0.03	0.009	0.03	0.015	0.009	0.012	0.007
Outlet lb/hr		200	60	200	100	60	100	60
Removal efficiency, %		98.7	99.6	98.3	99.2	99.5	99.2	99.5
Emission Control Level								
ng/joule		43	13	43	22	13	22	13
(lb./10^6 Btu)		(0.1)	(0.03)	(0.1)	(0.05)	(0.03)	(0.05)	(0.03)
Operating Cost Item	unit cost							
Direct Costs								
Operating Labor								
Operator	$10/man-hr	7,420	9,130	6,570	7,420	8,280	9,130	10,840
Supervision	$12/man-hr	2,520	2,520	2,520	2,520	2,520	2,520	2,520
Total		9,940	11,650	9,090	9,940	10,800	11,650	13,360
Maintenance								
Labor	$10/man-hr	9,820	10,980	11,420	12,730	14,030	11,150	11,750
Materials		2,300	3,070	3,360	4,230	5,110	3,180	3,590
Total		12,120	14,050	14,780	16,960	19,140	14,330	15,340
Replacement Parts		5,950	7,500	9,000	12,500	13,500	9,500	11,000
Utilities								
Electricity	$0.03/kWh	104,480	123,330	118,310	151,830	188,400	168,850	212,690
Total Direct Costs		132,490	156,530	151,180	191,230	231,840	204,330	253,290
Indirect Costs								
Overhead Charges								
Payroll	20% oper. lab.	1,990	2,330	1,820	1,990	2,160	2,330	2,680
Plant	50% lab. & maint.	11,030	12,860	11,930	13,450	14,970	12,990	14,350
Total		13,020	15,190	13,750	15,440	17,130	15,320	17,030
Capitalization Charges	17% of investment	419,580	527,950	566,250	730,690	819,590	638,860	751,500
Total Indirect Costs		$432,600	$543,140	$580,000	$746,130	$ 836,720	$654,180	$ 768,530
Total Annualized Cost		$565,090	$699,670	$731,180	$937,360	$1,068,560	$858,510	$1,020,920
Mills/kWh Operating Cost		0.32	0.40	0.42	0.54	0.61	0.49	0.58

Table 3-4. ANNUALIZED OPERATING COSTS FOR ELECTROSTATIC PRECIPITATORS ON 700 MW UTILITY BOILERS

(December 1976)

Basis: 8,760 operating hours per year at 65% capacity factor

Boiler Size, MW		700	700	700	700	700	700
Precipitator Location		Cold	Cold	Cold	Cold	Hot	Hot
Coal Type		Best	Best	Worst	Worst	Worst	Worst
Inlet and Outlet Gas Flow							
acfm		2,790,000	2,790,000	2,790,000	2,790,000	3,450,000	3,450,000
°F		350	350	350	350	700	700
scfm		1,825,000	1,825,000	1,825,000	1,825,000	1,580,000	1,580,000
Moisture, Vol.%		10	10	10	10	10	10
Particulate Loading							
Inlet gr/acf		2.32	2.32	1.76	1.76	1.43	1.43
Inlet lb/hr		55,600	55,600	42,200	42,200	42,200	42,200
Outlet gr/acf		0.03	0.009	0.03	0.009	0.012	0.007
Outlet lb/hr		700	210	700	210	350	210
Removal efficiency,%		98.7	99.6	98.3	99.5	99.2	99.5
Emission Control Level							
ng/joule		43	13	43	13	22	13
(lb./10^6 Btu)		(0.1)	(0.03)	(0.1)	(0.03)	(0.05)	(0.03)
Operating Cost Item	unit cost						
Direct Costs							
Operating Labor							
Operator	$10/man-hr	16,270	21,400	13,700	18,830	22,150	27,280
Supervision	$12/man-hr	3,480	3,480	3,480	3,480	3,780	3,780
Total		19,750	24,880	17,180	22,310	25,930	31,060
Maintenance							
Labor	$10/man-hr	31,050	33,000	34,590	43,710	34,740	38,840
Materials		8,250	9,690	10,620	17,300	10,210	12,950
Total		39,300	42,690	45,210	60,710	44,950	51,790
Replacement Parts		17,500	25,000	33,500	47,000	31,500	37,000
Utilities							
Electricity	$0.03/kWh	313,710	394,360	286,050	537,390	487,860	633,730
Total Direct Costs		390,260	486,920	381,940	667,410	590,240	753,580
Indirect Costs							
Overhead Charges							
Payroll	20% oper. lab.	3,950	4,980	3,430	4,460	5,190	6,210
Plant	50% lab. & maint.	29,530	33,780	31,200	41,510	35,440	41,430
Total		33,480	38,760	34,630	45,970	40,630	47,640
Capitalization Charges	17% capital investment	1,357,770	1,683,120	1,834,880	2,613,970	1,977,680	2,374,990
Total Indirect Costs		$1,391,250	$1,721,880	$1,869,510	$2,659,940	$2,018,310	$2,422,630
Total Annualized Cost		$1,781,510	$2,208,800	$2,251,450	$3,327,350	$2,608,550	$3,176,210
Mills/kWh Operating Cost		0.29	0.36	0.37	0.54	0.43	0.52

4.0 PROJECTED COMPLIANCE COSTS

4.1 METHOD OF PROJECTION

Data from the Federal Energy Administration and PEDCo files were used to project new boiler installations in the United States through the year 1985. These data were tabulated according to the size of the boilers and the type of coal to be used.[a] A summary is given in Table 4-1.

The investment and operating costs generated in Section 3 for 200- and 700-MW boiler precipitators were then used to compute investment and operating costs, weighted according to the proportion of the best and worst coal projected for use in boilers of these sizes. (See the sample calculations given in the Appendix.) Such weighted values were computed for each of the three emission-control levels considered and also for hot- and cold-side precipitator operation when using the worst coal, and for cold-side precipitators only for best coal use.

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[a] In the absence of other data, geographic location and coal heating value were employed to determine the type coal used at projected new installations. "Worst" coal was assumed for all locations west of the Mississippi River and those east of the Mississippi having coal heating values less than 10,000 or more than 12,500 Btu/lb. "Best" coal was assumed to be that used by plants east of the Mississippi River when the coal heating value ranged from 10,000 to 12,500 Btu/lb.

Table 4-1. SUMMARY OF COAL UTILIZATION FOR PROJECTED NEW UTILITY STEAM GENERATORS

Reproduced from best available copy.

Boiler size range MW	Best Coal Use		Worst Coal Use		Total capacity in size range MW	Percent of total projected capacity	Cumulative percentage of total capacity
	Capacity in size range MW	Percentage in size range	Capacity in size range MW	Percentage in size range			
More than 500	35,264	43.29	46,187	56.71	81,451	65.26	65.26
301 to 500	13,916	40.91	20,100	59.09	34,016	27.25	92.51
100 to 300	4,978	62.33	3,008	37.67	7,986	6.40	98.91
Less than 100	821	60.10	545	39.90	1,366	1.09	100.00
Totals	54,979	44.05	69,840	55.95	124,819	100.00	

Source of data for projection:

(1) "Trends in Power Plant Capacity and Utilization", Federal Energy Administration, December 1976.
(2) PEDCo data for FGD installations in the United States, December 1976.

Where cost data from Section 3 were incomplete, particularly at the 22 ng/joule (0.05 lb/10^6 Btu) emission level, interpolation was required to compute weighted values.

4.2 PROJECTED INVESTMENT COSTS

The projected precipitator investment costs for compliance with the various particulate emission control levels with cold- and hot-side precipitators are presented in Figures 4-1 and 4-2, respectively. These graphs were prepared by plotting weighted investment values in $/kW versus the percentage of new 200- and 700-MW boilers projected.

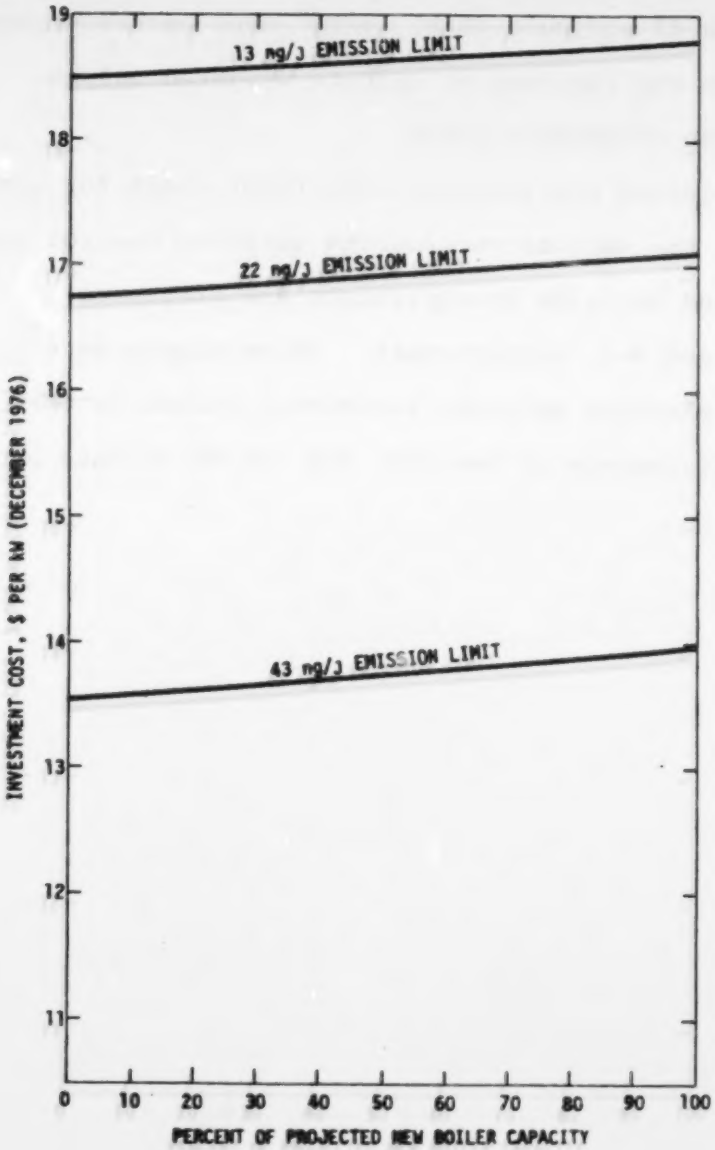

Figure 4-1. Cold side precipitator investment costs for projected new boiler capacity.

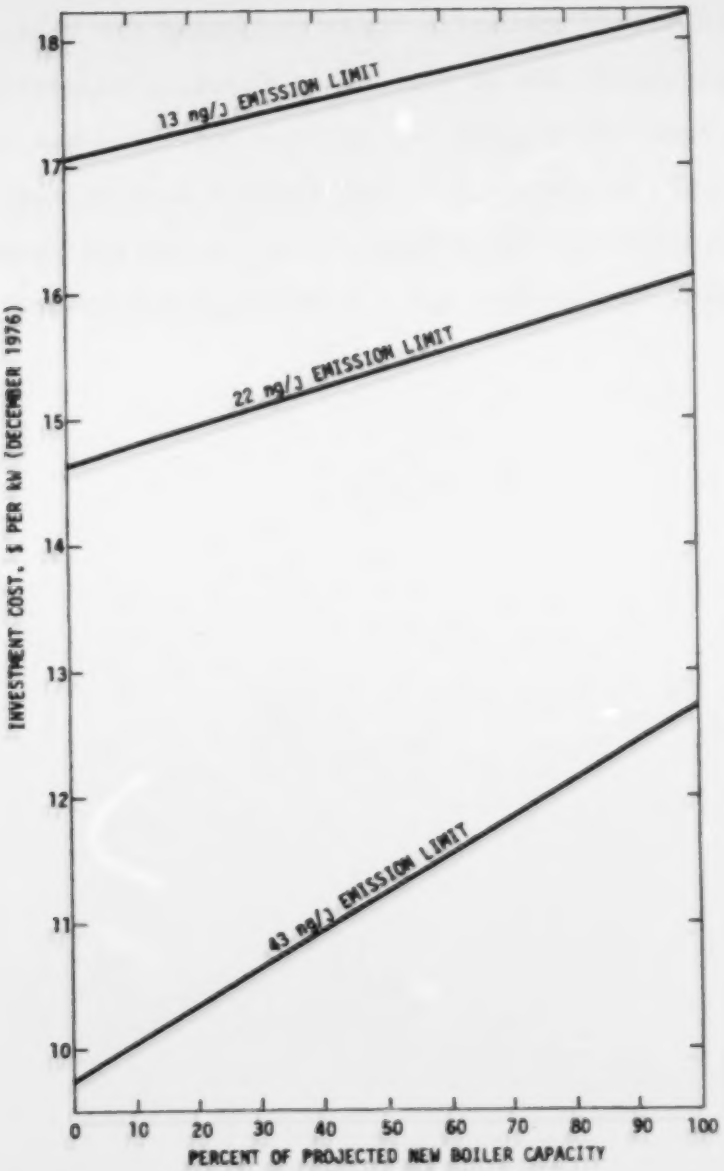

Figure 4-2. Hot side precipitator investment costs for projected new boiler capacity.

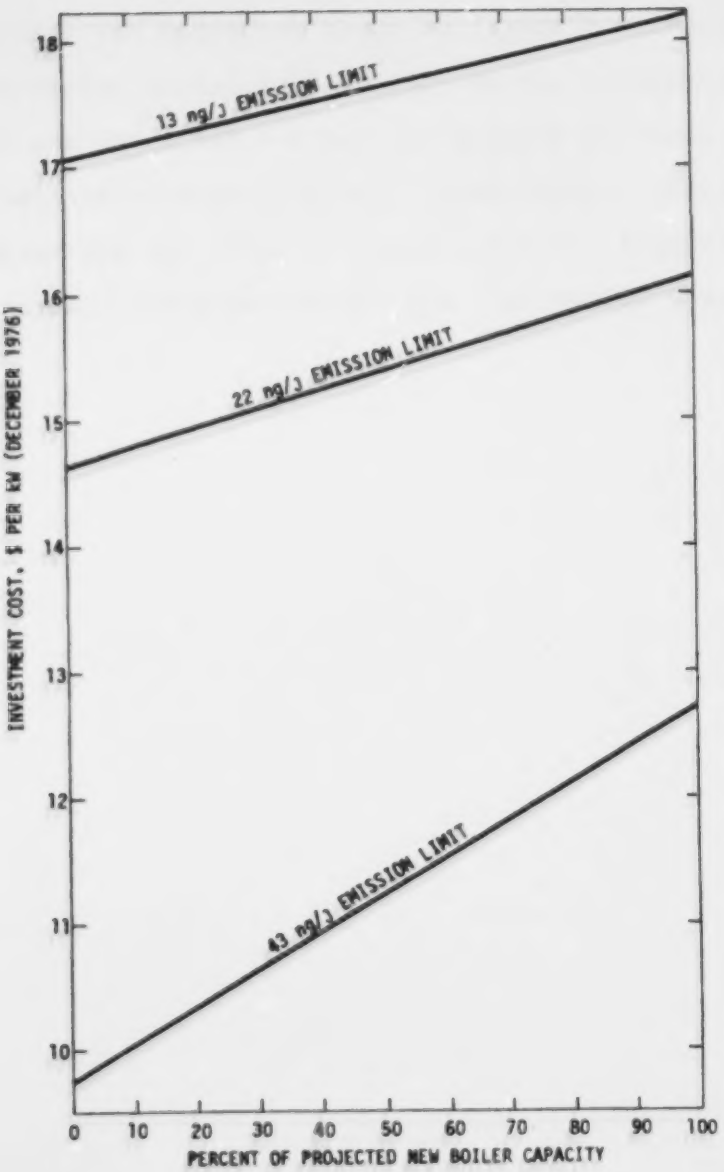

Figure 4-2. Hot side precipitator investment costs for projected new boiler capacity.

4.3 PROJECTED ANNUALIZED OPERATING COSTS

The annualized operating costs projected for electrostatic precipitator use at various particulate emission levels are shown in Figures 4-3 and 4-4 for cold- and hot-side locations, respectively. The figures were derived from plots of weighted operating costs in mills per kWh versus the percentage of new 200- and 700-MW boilers projected.

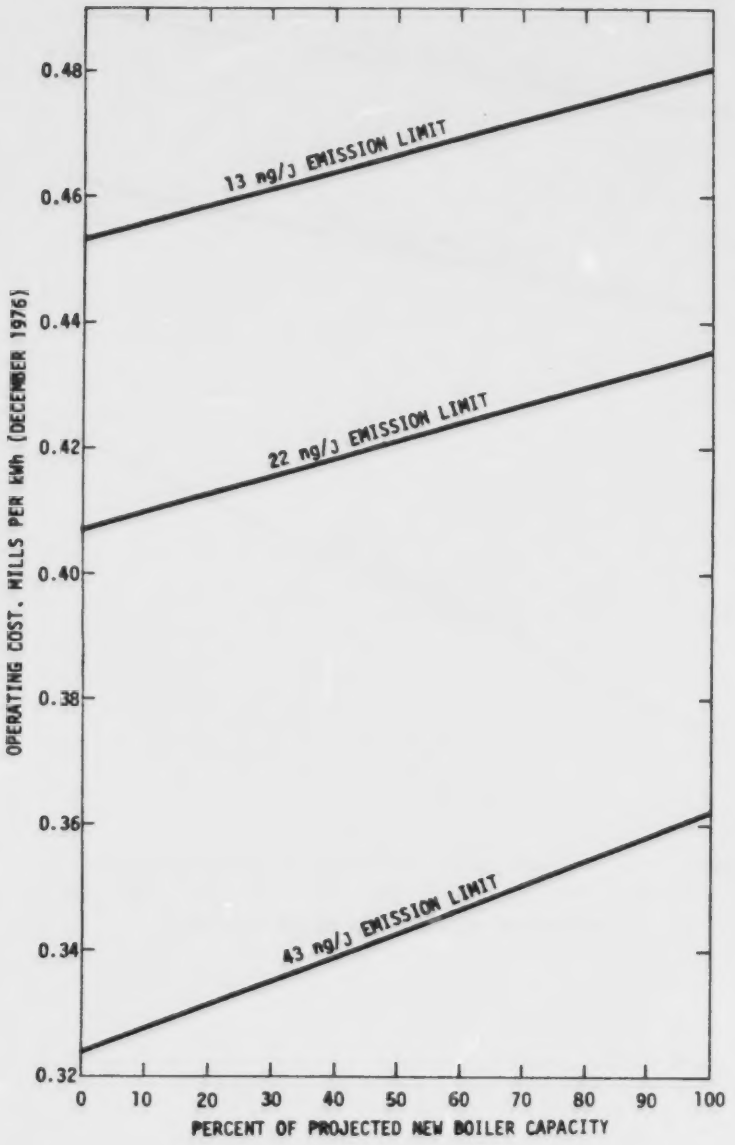

Figure 4-3. Cold side precipitator annualized operating costs for projected new boiler capacity.

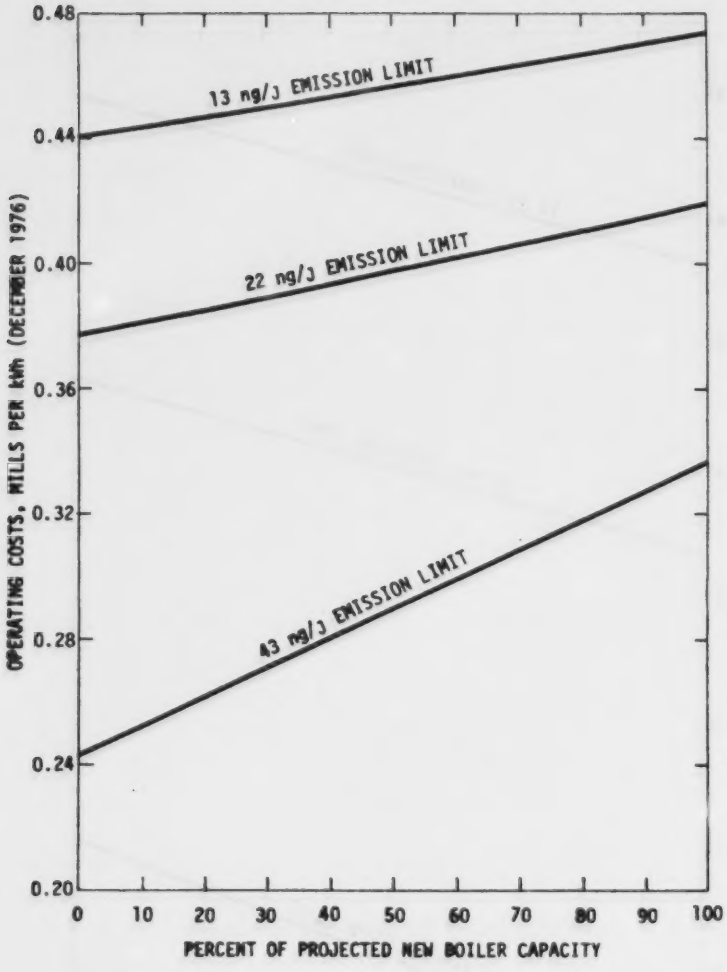

Figure 4-4. Hot side precipitator annualized operating costs for projected new boiler capacity.

APPENDIX A

ELECTROSTATIC PRECIPITATOR SPECIFICATIONS

SAMPLE CALCULATIONS

Company: IGCI
Project: 68-02-1473
Task No.: 17
Date:

ELECTROSTATIC PRECIPITATOR SPECIFICATION FOR LARGE COAL-FIRED STEAM GENERATORS

An electrostatic precipitator is to remove solids from the exhaust gas of a large coal-fired steam generator. Systems shall be quoted complete, including the following:

1. Electrostatic precipitator
2. Inlet plenum
3. Outlet plenum
4. Air distribution turning vanes
5. Structural steel for installation of the precipitator at grade
6. Insulation including weatherproof lagging to match temperature to be 2" thick on 350° services and 4" thick on 700° services
7. Other necessary auxiliary equipment
8. Electrical installation work.

Draft fans and ash handling equipment and controls are not included in this specification.

Details

1. The precipitator is to continuously reduce the solids content of the gas to the levels specified on the attached data sheets.
2. The precipitator shall be a single-stage plate-type unit with inlet face velocity not to exceed 5.5 FPS for 700°F services, and not to exceed 4.5 FPS for 350°F services.
3. The material of construction of all parts of the system shall be mild steel A-36, minimum 3/16" thickness.

4. Electrical power at 460v, 3 phase, 60 cycle; and 110v, 1 phase, 60 cycle is available in sufficient quantity at the site. Automatic voltage controls shall be provided for each field. A safety interlock system shall be provided so that no access to high voltage equipment is possible without first de-energizing all fields.

5. A heated, pressurized penthouse design shall be employed.

6. Thirteen system variations are specified on the attached data sheets. Each is specified for use with either of two grades of coal. Coal analyses are:

	Best	Worst
Sulfur, %	4.0	0.5
Moisture, %	15.0	28.1
Ash, %	10.0	5.9
Ash Compounds		
Sodium	-	low
Iron	-	low
Calcium	-	high
Heat value		
Mega joules/kg (Btu/lb)	24.89 (10,700)	19.36 (8,322)

7. A model study for the precipitator gas distribution system will not be required.

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILERS SIZE)

Data Sheet No. 17-1
Project No. 68-02-1473
Task No. 17

Equipment Classification		202
Coal Sulfur Content		4.0%
Inlet and outlet gas flow		
ACFM		798,000
°F		350
SCFM		521,000
Moisture, Vol. %		10
Contaminant loading		
Inlet, gr/ACF		2.32
Inlet, lb/hr		15,900
Outlet, gr/ACF		0.009
Outlet, lb/hr		60
Cleaning efficiency		99.6%
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-1A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT			202 4.0%
Inlet & outlet gas flow			
ACFM			798,000
°F			350
SCFM			521,000
Moisture, Vol. %			10
Contaminant loading			
Inlet, gr/ACF			2.32
Inlet, lb/hr			15,900
Outlet, gr/ACF			0.009
Outlet, lb/hr			60
Cleaning efficiency			99.6%
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

Operating costs, all systems, to be based on annual operation of 8760 hours per year @ 65% capacity factor.

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-2
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		204 0.5%
Inlet and outlet gas flow		
ACFM		798,000
°F		350
SCFM		521,000
Moisture, Vol. %		10
Contaminant loading		
Inlet, gr/ACF		1.76
Inlet, lb/hr		12,000
Outlet, gr/ACF		0.015
Outlet, lb/hr		100
Cleaning efficiency		99.2%
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-2A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION			204
COAL SULFUR CONTENT			0.5%
Inlet & outlet gas flow			
ACFM			798,000
°F			350
SCFM			521,000
Moisture, Vol. %			10
Contaminant loading			
Inlet, gr/ACF			1.76
Inlet, lb/hr			12,000
Outlet, gr/ACF			0.015
Outlet, lb/hr			100
Cleaning efficiency			99.2%
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-3
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION - COAL SULFUR CONTENT	205 0.5%	
Inlet and outlet gas flow		
ACFM	798,000	
°F	350	
SCFM	521,000	
Moisture, Vol. %	10	
Contaminant loading		
Inlet, gr/ACF	1.76	
Inlet, lb/hr	12,000	
Outlet, gr/ACF	0.009	
Outlet, lb/hr	60	
Cleaning efficiency	99.5%	
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-3A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		205 0.5%	
Inlet & outlet gas flow			
ACFM		798,000	
°F		350	
SCFM		521,000	
Moisture, Vol. %		10	
Contaminant loading			
Inlet, gr/ACF		1.76	
Inlet, lb/hr		12,000	
Outlet, gr/ACF		0.009	
Outlet, lb/hr		60	
Cleaning efficiency		99.5%	
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-4
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT	207 0.5%	208 0.5%
Inlet and outlet gas flow		
ACFM	985,000	985,000
°F	700	700
SCFM	450,000	450,000
Moisture, Vol. %	10	10
Contaminant loading		
Inlet, gr/ACF	1.43	1.43
Inlet, lb/hr	12,000	12,000
Outlet, gr/ACF	0.012	0.007
Outlet, lb/hr	100	60
Cleaning efficiency	99.2%	99.5%
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-4A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		207 0.5%	208 0.5%
Inlet & outlet gas flow			
ACFM		985,000	985,000
°F		700	700
SCFM		450,000	450,000
Moisture, Vol. %		10	10
Contaminant loading			
Inlet, gr/ACF		1.43	1.43
Inlet, lb/hr		12,000	12,000
Outlet, gr/ACF		0.012	0.007
Outlet, lb/hr		100	60
Cleaning efficiency		99.2%	99.5%
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-5
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT	701 4.0%	702 4.0%
Inlet and outlet gas flow		
ACFM	2,790,000	2,790,000
°F	350	350
SCFM	1,825,000	1,825,000
Moisture, Vol. %	10	10
Contaminant loading		
Inlet, gr/ACF	2.32	2.32
Inlet, lb/hr	55,600	55,600
Outlet, gr/ACF	0.03	0.009
Outlet, lb/hr	700	210
Cleaning efficiency	98.7%	99.6%
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-5A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		701 4.0%	702 4.0%
Inlet & outlet gas flow			
ACFM		2,790,000	2,790,000
°F		350	350
SCFM		1,825,000	1,825,000
Moisture, Vol. %		10	10
Contaminant loading			
Inlet, gr/ACF		2.32	2.32
Inlet, lb/hr		55,600	55,600
Outlet, gr/ACF		0.03	0.009
Outlet, lb/hr		700	210
Cleaning efficiency		98.7%	99.6%
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-7
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT	705 0.5%	
Inlet and outlet gas flow		
ACFM	2,790,000	
°F	350	
SCFM	1,825,000	
Moisture, Vol. %	10	
Contaminant loading		
Inlet, gr/ACF	1.76	
Inlet, lb/hr	42,200	
Outlet, gr/ACF	0.009	
Outlet, lb/hr	210	
Cleaning efficiency	99.5%	
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-7A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		705 0.5%	
Inlet & outlet gas flow			
ACFM		2,790,000	
°F		350	
SCFM		1,825,000	
Moisture, Vol. %		10	
Contaminant loading			
Inlet, gr/ACF		1.76	
Inlet, lb/hr		42,200	
Outlet, gr/ACF		0.009	
Outlet, lb/hr		210	
Cleaning efficiency		99.5%	
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-8
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT	707 0.5%	708 0.5%
Inlet and outlet gas flow		
ACFM	3,450,000	3,450,000
°F	700	700
SCFM	1,580,000	1,580,000
Moisture, Vol. %	10	10
Contaminant loading		
Inlet, gr/ACF	1.43	1.43
Inlet, lb/hr	42,200	42,200
Outlet, gr/ACF	0.012	0.007
Outlet, lb/hr	350	210
Cleaning efficiency	99.2%	99.5%
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-8A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		707 0.5%	708 0.5%
Inlet & outlet gas flow			
ACFM		3,450,000	3,450,000
°F		700	700
SCFM		1,580,000	1,580,000
Moisture, Vol. %		10	10
Contaminant loading			
Inlet, gr/ACF		1.43	1.43
Inlet, lb/hr		42,200	42,200
Outlet, gr/ACF		0.012	0.007
Outlet, lb/hr		350	210
Cleaning efficiency		99.2%	99.5%
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-9
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT	201 4.0%	203 0.5%
Inlet and outlet gas flow		
ACFM	798,000	798,000
°F	350	350
SCFM	521,000	521,000
Moisture, Vol. %	10	10
Contaminant loading		
Inlet, gr/ACF	2.32	1.76
Inlet, lb/hr	15,900	12,000
Outlet, gr/ACF	0.03	0.03
Outlet, lb/hr	200	200
Cleaning efficiency	98.7%	98.3%
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(200 MW BOILER SIZE)

Data Sheet No. 17-9A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		201 4.0%	203 0.5%
Inlet & outlet gas flow			
ACFM		798,000	798,000
°F		350	350
SCFM		521,000	521,000
Moisture, Vol. %		10	10
Contaminant loading			
Inlet, gr/ACF		2.32	1.76
Inlet, lb/hr		15,900	12,000
Outlet, gr/ACF		0.03	0.03
Outlet, lb/hr		200	200
Cleaning efficiency		98.7%	98.3%
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

Operating costs, all systems, to be based on annual operation of 8760 hours per year @65% factor.

CAPITAL COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-10
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT	703 0.5%	
Inlet and outlet gas flow		
ACFM	2,790,000	
°F	350	
SCFM	1,825,000	
Moisture, Vol. %	10	
Contaminant loading		
Inlet, gr/ACF	1.76	
Inlet, lb/hr	42,200	
Outlet, gr/ACF	0.03	
Outlet, lb/hr	700	
Cleaning efficiency	98.3%	
Gas cleaning equipment cost		
Cost of auxiliaries		
Total equipment cost		
Installation costs, direct*		
Foundation and supports		
Duct work		
Stack		
Piping		
Insulation		
Painting		
Electrical		
Total direct costs		
Installation costs, indirect		
Engineering		
Constr. and field expense		
Construction fees		
Start-up		
Performance test		
Contingencies		
Total Indirect costs		
Turnkey cost		

* Where specified

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ANNUAL OPERATING COST DATA
ELECTROSTATIC PRECIPITATORS
FOR LARGE COAL-FIRED STEAM
GENERATORS
(700 MW BOILER SIZE)

Data Sheet No. 17-10A
Project No. 68-02-1473
Task No. 17

EQUIPMENT CLASSIFICATION COAL SULFUR CONTENT		703 0.5%	
Inlet & outlet gas flow			
ACFM		2,790,000	
°F		350	
SCFM		1,825,000	
Moisture, Vol. %		10	
Contaminant loading			
Inlet, gr/ACF		1.76	
Inlet, lb/hr		42,200	
Outlet, gr/ACF		0.03	
Outlet, lb/hr		700	
Cleaning efficiency		98.3%	
Operating cost item	Unit cost		
Direct costs:			
Operating labor			
Operator	$10/manhour		
Supervisor	$12/manhour		
Total			
Maintenance			
Labor	$10/manhour		
Materials			
Total			
Replacement parts			
Utilities			
Electricity	$0.03/kWh		
Total			
Total Direct costs			
Capital charges			
Total annual cost			

Operating costs, all systems, to be based on annual operation of 8760 hours per year @65% factor.

SAMPLE CALCULATIONS TO DETERMINE

WEIGHTED INVESTMENT AND OPERATING COSTS

I. BASIS FOR COMPUTATIONS:

a) 43 ng/joule emission control level

b) Use of cold side electrostatic precipitators for both best and worst coal.

II. WEIGHTED INVESTMENT COSTS

a) At 200 MW level
Per Table 3-1, the unit costs are
For Best Coal: $12.34/kW
For Worst Coal: $16.65/kW
Per Table 4-1,
For 100 to 300 MW range, it is projected that the coal mix to be used is 62.33% Best Coal and 37.67% Worst Coal.

Wtd. Inv. = (Best Amt.)(Unit cost) + (Worst Amt.) (Unit cost)

Substituting values in this equation,

Wtd. Inv. = (0.6233)($12.34/kW) + (0.3767)($16.65/kW)
= 7.69 + 6.27
= $13.96/kW

b) At 700 MW level
Per Table 3-2, the unit costs are
For Best Coal: $11.41/kW
For Worst Coal: $15.42/kW
Per Table 4-1, it is projected that for >500 MW the coal mix to be used is 43.29% Best Coal and 56.71% Worst Coal.

Wtd. Inv. = (Best Amt.)(Unit cost) +
(Worst Amt.) (Unit cost)

Substituting values in this equation,

Wtd. Inv. Cost = (0.4329)($11.41/kW) +
(0.5671)($15.42/kW)
= 4.94 + 8.74
= $13.68/kW

III. WEIGHTED OPERATING COSTS

a) At 200 MW level
Per Table 3-3, the unit costs are
For Best Coal: 0.32 mills/kWh
For Worst Coal: 0.42 mills/kWh
Per Table 4-1, for 100 to 300 MW range, it is projected that the coal mix to be used is 62.33% Best Coal and 37.67% Worst Coal.

Wtd. Op. Cost = (Best Amt.)(Unit cost) +
(Worst Amt.) (Unit cost)

Substituting values in the equation,

Wtd. Op. Cost = (0.6233)(0.32 mills/kWh) +
(0.3767)(0.42 mills/kWh)
= 0.20 + 0.16
= 0.36 mills/kWh

b) At 700 MW level
Per Table 3-4, the units costs are
For Best Coal: 0.29 mills/kWh
For Worst Coal: 0.37 mills/kWh
Per Table 4-1, for >500 MW range, it is projected that the coal mix to be used is 43.29% Best Coal and 56.71% Worst Coal

Wtd. Op. Cost = (Best Amt.)(Unit cost) +
(Worst Amt.) (Unit cost)

Substituting values in the equation,

Wtd. Op. Cost = (0.4329)(0.29) + (0.5671)(0.37)
= 0.126 + 0.210
= 0.336 mills/kWh